Lead: Avichal Mehra (NWS/EMC)

1.0 Ocean Model

1.1 State of the Science

Presently, NOAA/NCEP has two different ocean modeling approaches, two wave modeling efforts, and two ice modeling approaches one at NCEP and one at OAR/GFDL which requires additional development and advancement efforts. The first ocean modeling approach is the Modular Ocean Model (MOM) series models and the corresponding Global Ocean Data Assimilation System (GODAS) data assimilation approach, and the second is based on the HYbrid Coordinate Ocean Model (HYCOM) and is intended to include the Navy Coupled Ocean Data Assimilation (NCODA) data assimilation systems, both mostly developed at U.S. Naval Research Laboratory (NRL). Normally, EMC would not want to support two different modeling systems for similar purposes (ocean modeling in this case). However, MOM presently targets seasonal time scales and receives support from GFDL, whereas HYCOM/NCODA targets weather time scales and receives support from the Navy and academia. MOM and GODAS support has traditionally been associated with the Climate Forecast System (CFS) models, have in-house base support, and are expected to obtain continued support for CFS-v3 development. The R2O Initiative can target HYCOM/NCODA to fill in the gap for support, as well as operational and pre-operational capabilities of these models at EMC. Deliverables are directly linked to operational implementations including some operational implementation of initial capabilities, and fine tuning of model products based on evolving user requests. Below are tentative deliverables per system, organized per year. Actual implementation (delivery) dates will be worked out in collaboration with NCEP Central Operations (NCO) in the context of a holistic sustainable implementation schedule.

1.2 Ocean Model Milestones and Outcomes for Near-Term Objectives

- Pre-operational and operational upgrade capabilities to the Real-Time Ocean Forecast System (RTOFS)-Global Model and the RTOFS-Atlantic.
    - **Lead Organization:** NCEP
    - **Activities:** Upgrade is scheduled for year 1, however, the RTOFS-Global Model transition to Navy GOFS 3.1 will occur in lockstep with Navy's upgrade and is dependent upon the timing of the upgrade at the Navy.
    - **Milestones and deliverables:**
        - Operational upgrades of RTOFS-Global and –Atlantic. RTOFS-Atlantic will be nested in RTOFS-Global for the first time.
        - Upgrades to the real-time data in the existing data assimilation schemes as new data sources emerge and old data sources expire.
        - Upgrades to products as requested by users such as adding GRIB2 (GRIdded Binary data) fields for use in NOAA's Advanced Weather Interactive Processing System (AWIPS).
        - Year 2 input and product upgrades will be determined at the end of year 1.
        - Transition of operational codes to Task 4 Cray (deposing on delivery of system)
    - **Anticipated collaborating organizations:** Navy
    - **Priority:** High
    - **Duration:** 2 years
    - **Points of contact:** Hendrik Tolman

- Pre-operational and operational upgrade capabilities to the Real-Time Ocean Forecast System (RTOFS)-NEMS.
    - **Lead Organization:** NCEP
    - **Activities:** Upgrade ROFS-NEMS, evaluate incorporation of ice model and leverage Arctic coupled modeling projects
    - **Milestones and deliverables:**
        - Finalize the development of 0.25° global RTOFS-NEMS model for coupled HYCOM-GSM-Sea Ice model runs
        - Evaluate ice modeling in this system (NEMS GFDL version of the Los Alamos sea ice model (CICE) or EMC KISS models)
        - Perform initial experiment with HYCOM-GFS-Sea Ice or HYCOM-GEFS-Sea Ice (Global Ensemble Forecast System) coupled model, and assess the impact on traditional forecasts skills
    - **Anticipated collaborating organizations:** ESRL
    - **Priority:** High
    - **Duration:** 2 years
    - **Points of contact:** Hendrik Tolman

- Operational capabilities in the RTOFS-HWRF (Hurricane Weather Research and Forecast System) Model
    - **Lead Organization:** NCEP
    - **Activities:** Couple HWRF and HYCOM ocean model
    - **Milestones and deliverables:**
        - Year 1: Tentative first operational implementation of an HYCOM-HWRF coupled model system is tentatively schedule for FY16
        - Year 2: First upgrade of the HYCOM-HWRF system, potentially adding wave model coupling.
    - **Anticipated collaborating organizations:**
    - **Priority:** High
    - **Duration:** 2 years
    - **Points of contact:** Hendrik Tolman

1.3 Ocean Data Assimilation Milestones and Outcomes for Near-Term Objectives

The initial data assimilation capability for the RTOFS (HYCOM) models needs to be addressed. In 2013, EMC signed a Memorandum of Understanding (MOU) with NRL to port NCODA to EMC, thus avoiding the need for a daily data feed from NRL to EMC, as well as the need for EMC to remain in lockstep with NAVO/NRL with respect to model development. A second need is in transferring data assimilation (DA) approaches for the coupled HWRF-HYCOM model from HFIP to the R2O Initiative. The two main goals for the first two years under R2O is to 1) Implement NCODA at EMC, and 2) Provide ocean DA for coupled HWRF-HYCOM model. As NCODA reaches implementation at EMC, development and research priorities will be addressed.

- Implement NCODA at EMC
    - **Lead Organization: EMC**
    - **Activities:** The NCODA Deliverables for first 24 months would address work that has started, but with limited support, and will be increased incrementally. The 0 month point for this plan is effectively the start of FY15Q1, as the code was delivered to EMC late FY14Q4.

- **Milestones and deliverables:**
  - 6 months: Port NCODA code to WCOSS for compilation, running and profiling, and run with canned data sets provided by the Navy. Prepare a plan for converting Navy data streams to NCO data tank standards, procedures and data. Provide NCO with a request for data used by NCODA but not yet in NCO data tanks.
  - 12 months: 35% of the data streams will be converted from Navy protocols to NCO protocols. The design and prototype of diagnostics, along with prototype scripts for data handling in preparation for low-resolution assimilation experiments, will be prepared.
  - 18 months: 70% of data streams will be converted from Navy protocols to NCO protocols. The prototype setup for low resolution assimilation experiments will be completed with initial results reported.
  - 24 months: The goal is to finish data stream conversion to NCO protocols, and have real-time low-resolution hindcast. Nowcast running in real time. Experiments with full resolution assimilation will be started. Note that full resolution assimilation requires Phase II WCOSS to be in place at expected petaflop capability. The deliverables include planning conservatively for the availability of Phase II, but it may be possible to do stratified high-resolution runs earlier if Phase II is available, and if data stream conversion to NCO standards allows this.
  - 30 months: Expectation that the system is ready for the operational implementation of NCODA for RTOFS-Global, with actual operational implementation dependent on NCO implementation schedule.
- **Anticipated collaborating organizations:** TBD
- **Priority:** High
- **Duration:** 2.5 years
- **Points of contact:** Hendrik Tolman

- Provide ocean DA for coupled HWRF-HYCOM model.
  - **Lead Organization:** EMC
  - **Activities:** Ongoing work that can be transitioned from HFIP to the R2O Initiative.
  - **Milestones and deliverables:** The tentative first operational implementation of HYCOM-HWRF system with ocean DA of Sea Surface Temperature (SST) and Salinity will take place by May 2015. By May 2016, the first upgrade of HYCOM-HWRF system adding Sea Surface Height (SSH), and Temperature-Salinity profiles to assimilation will occur.
  - **Anticipated collaborating organizations:** TBD
  - **Priority:** Medium
  - **Duration:** 1 year
  - **Points of contact:** Hendrik Tolman

- An Operational Hybrid 3DVar/EnKF Ocean Assimilation System at NCEP
  - **Lead Organization:** Steve Penny,- Lead PI, University of Maryland, Co-I: Jim Carton, Eugenia Kalnay
  - **Activities:** Transition the research Hybrid 3DVar/LETKF global ocean data assimilation system to operations via incorporation into the CFSv3 software suite and perform validation tests of the system accuracy and reliability. A secondary goal is to leverage the wide range of opportunities afforded by this new ensemble-based ocean data assimilation system
  - **Milestones and deliverables:** Year 1: Implementation of Hybrid in CFSv3 with direct

assimilation of radiances for SST with accompanying report. Year 2: New observation types and impact assessment. Report documenting the implementation of direct satellite measurements relating to SSH into the Hybrid 3DVar/LETKF ocean assimilation, and a complete observational impact study using new observation types.

- **Anticipated collaborating organizations:** EMC - Dave Behringer, Jack Woollen, CPC – Yan Xue
- **Priority:** High
- **Duration:** 05/01/2015 – 04/30/2017
- **Points of contact:** Hendrik Tolman

1.4 Milestones and Outcomes for Long-Term Objectives

The long term objective is a unified modeling approach integrating a suite of selected ocean, wave, arctic, and sea ice models into a coupled system capable of improved predictability.

2.0 Wave Model

2.1 State of the Science

Currently there are two wave modeling efforts. WAVEWATCH III is a third generation wave model developed at NOAA/NCEP and is evolving from a wave model into a wave modeling framework, which allows for easy development of additional physical and numerical approaches to wave modeling. The other wave model is the Nearshore Wave Prediction System (NWPS), also currently being developed, and is designed to provide routine and on-demand, high-resolution nearshore wave model guidance to coastal NWS forecasters. Three gaps have been identified for modification for the wave models to be incorporated into the new NGGPS.

1. Enable wave-coupling in all EMC/NCEP models. This requires finishing the NEMS / ESMF / NUOPC wrapper for the WAVEWATCH III model. This project has just started and will need additional support to bring to full fruition.

2. Although wave requirements have shifted to coastal modeling, where coastal wave modeling is reasonably covered with the Nearshore Wave Prediction System (NWPS), NWPS needs to become a fully coupled wave-surge capability on unstructured grids. This will require WAVEWATCH III to be coupled to 2 and 3D ocean circulation models, ADCIR (ADvanced CIRCulation model) and FVCOM (Finite Volume Coastal Ocean Model). The unstructured-grid wave-surge coupling needs additional resources to bring this to operations in the NWS and inside NWPS. Note that NWPS also supports SWAN (Simulating WAves Nearshore) as a wave model, for which the coupling is already available. Long term Operation and Management (O & M) considerations may move towards a full WAVEWATCH III based system rather than supporting multiple wave models.

3. WAVEWATCH III is a community model, where research may be leveraged with partners in the Federal Government and academia, as has been proven in a recent National Oceanographic Partnership Program (NOPP) project, resulting in an overhaul of most wave model physics. To gain the maximum benefit from this community modeling effort, EMC would need a full time WW3 code manager, dedicated to supporting community modeling.

2.2 Wave Model Milestones and Outcomes for Near-Term Objectives

The three identified gaps result in three separate projects, with three separate sets of deliverables for NEMS, NWPS and code management.

- Wave model-coupling deliverables for NEMS include:
    - **Lead Organization:** EMC
    - **Activities:** Wrapper and "solo coupler" prepared in NEMS, additional coupling dependent on the progress of related projects
    - **Milestones and deliverables:**
        - The wrapper will be ready as well as a "solo coupler" in NEMS by six months. By 12 months, there will be a demonstration of a multi_1 wave model one-way coupled with GFS or GEFS, avoiding the need for coupling in near-real-time through the file system, and the hand-over to O&M for operational implementation.
        - The focus for year 2 will depend on progress in other projects. Actual projects and deliverables will be determined at the end of year 1, with the potential projects and deliverables selecting one of the four listed below:
            1. Focus on GFS: Experiment with two-way coupling to see if it can improve both weather and wave forecasting.
            2. Focus on Arctic modeling: Add waves to prototype coupled Arctic model.
            3. Start wave-ocean coupling to improve ocean mixed-layer forecast by adding Langmuir and Stokes-Coriolis mixing to ocean model.
            4. Improve wave forecast by adding wave-current interactions.
        - Beyond year 2, HWRF is scheduled to be tentatively converted to NEMS by early FY16. Once this capability is available, the next high-priority wave coupling effort will be with the HWRF. This is potentially high-impact for operations, as an "all-storm-in-one" HWRF allows NWS to have the hurricane wave model directly included in HWRF, instead of running it downstream as is done now.
    - **Anticipated collaborating organizations:**
    - **Priority:** High
    - **Duration:** 3 years
    - **Points of contact:** Hendrik Tolman

- Wave model deliverables for Nearshore Wave Prediction System (NWPS) to be fully coupled wave surge capable on unstructured grid are:
    - **Lead Organization:** EMC
    - **Activities:** Couple WAVEWATCHIII to Adcirc and FVCOM
    - **Milestones and deliverables:**
        - Within the next six months, have a prototype WW3-Adcirc coupling to demonstrate the quality of the model and estimate future resource needs.
        - By 12 months, the coupled model will be included in NWPS baseline software.
        - Within 24 months, six Weather Forecast Offices (WFO) will be set up with an unstructured grid coupled WW3-Adcirc (or SWAN-Adcirc) model.
    - **Anticipated collaborating organizations:** TBD

- **Priority:** Low
- **Duration:** 2 years
- **Points of contact:** Hendrik Tolman

- Management of code for WAVEWATCHIII
  - **Lead Organization:** EMC
  - **Activities:** Hire code manager to leverage research and community model development
  - **Milestones and deliverables:** Implement contributions to the WAVEWATCHIII trunk model including full regression testing and documentation, and identification of target upgrades
  - **Anticipated collaborating organizations:** TBD
  - **Priority:** Medium
  - **Duration:** full-time
  - **Points of contact:** Hendrik Tolman

2.3 Wave Data Assimilation Milestones and Outcomes for Near-Term Objectives

The wind wave model is different from most major models at NWS as it represents a forced and damped problem, rather than an initial value problem such as short time scale weather, and ocean models. For this reason DA in wave modeling is not as critical as in weather modeling. Wave DA was operational in the late 1990s and early 2000s, but became defunct as the system did not keep up with new altimeter data streams, and was ultimately not ported to new operational computers. Adding wave DA back into the operational systems is important for three reasons:

1. Improving short-term forecasts, i.e., wind seas in general for 6-12 hour forecast, depending on spatial scale of problem, and swells for potentially up to 2 weeks for long swells on the Pacific Ocean.

2. Justification for satellite observations (altimeter waves, Synthetic Aperture Radar (SAR) spectra). These observations are critical for off-line wave model validation and development, but only seem to receive attention if used in real time. Hence, adding data assimilation to wave models is politically important to protect critical sources of observations.

3. Initial experiments with assessing coupled errors in wind and waves using EnKF methods indicate a strong relation between the two. This implies that future coupled ocean-wave-weather assimilation (starting with wave-wind) can potentially improve each system more than traditional decoupled assimilation. Wave DA could this potentially help weather DA directly.

Presently, wave DA is being re-established into NCEP operations through Joint Center for Satellite Data Assimilation (JCSDA) funding for altimeter wave data quality control (QC), as well as preparation to assimilate wave height data through the Gridpoint Statistical Interpolation (GSI). This project is funded for initial development of the QC and GSI approaches, but not for full implementation. Hence, the first step is to re-introduce wave DA into the operational global model, tentatively using the GSI and the new QC algorithms. After this, the following expansions can be considered in the Global Hurricane wave model, which is a high priority, with minimal effort as the model is very similar to regular global model. The global wave ensemble expansion can be considered a high priority as well, but more complex effort is involved as the model requires consideration of generating / maintaining ensemble spread. The Great Lakes model, is a low priority, as short residence time of wave ln GL will result in quickly losing impact of DA, and hence impact only for short-term forecasts (expected < 6-12h).

After this, technical improvements are needed for the simple initial DA techniques. The following improvements are expected to all yield significant benefits for the wave models, as well as for future coupled systems.

1. Develop wave-system based DA (Initial DA only considers overall wave height of all wave systems combined).
2. Consider assimilation of spectral wave data from buoys or from SAR. Presently, only overall wave height is assimilated.
3. Develop a hybrid DA system similar to that used in the GODAS. Initial work on this has already been started by our partners in academia.

- Selection of wave data assimilation projects from the list above will be partially determined by scientist's background and knowledge of the EnKF and Hybrid approaches.
    - **Lead Organization:** EMC
    - **Activities:** Improvements to the wave data assimilation techniques
    - **Milestones and deliverables:**
        - Six month deliverables include having the parallel wave DA system up and running and ready for implementation. At this stage, the implementation will be done by existing O&M wave support. DA intended for multi_1 global wave model will be in place and possibly also adopted for multi_2 global hurricane wave model.
        - The proof of concept for hybrid wave DA system for overall significant wave heights will be delivered by 18 months.
        - By 24 months, it is expected to have a full pre-operational prototype for the hybrid system, and there will be a hand-over to wave O&M support.
    - **Anticipated collaborating organizations:** TBD
    - **Priority:** Medium
    - **Duration:** 2 years
    - **Points of contact:** Hendrik Tolman

3.0 Arctic Model

With the increased size of ice-free zones in the Arctic summer, the NWS has expanded forecast responsibilities in these areas. However, present advanced models such at the Navy Arctic Cap Nowcast Forecast System (ACNFS) have been shown to have no skill over ice persistence beyond a 3 day forecast. A review of literature and local experience shows that ice predictability is strongly linked to the accuracy of heat fluxes into the ice/ocean. Biases as little as 10 W/m^2 result in an annual growth or melting of up to 1m of ice thickness. Our experience with simple drift models show that such models also provide more predictability of the location of the ice edge than a full dynamical model like the ACNFS. Furthermore considering that the ice has a major impact on air-sea fluxes, an accurate representation of dominant processes for ice modeling requires a coupled atmosphere-ocean model with a common ice representation (i.e., coupled atmosphere-ocean-ice model), with an explicit control of flux biases. Furthermore, the dependence on flux errors suggests that suppression of random flux errors due to ensemble averaging is expected to also increase predictability of ice coverage. From a pure ice modeling perspective, this implies that a simple ice model using thermodynamics and simple ice drift approaches is sufficient for creating predictability, and is much easier to control than a full physical model. Such a model is under development at EMC (KISS). There is also concern that conventional validation techniques for ice concentrations do not adequately address with accuracy the movement of the ice edge, which for most users is the most critical aspect of an ice forecast. Hence, development of proper metrics for validating ice concentrations and/or ice edge location should be an integral part of the development of a modeling systems focusing on Arctic ice.

The above considerations would lead to a modeling system that is unique compared to existing modeling systems in five ways:

1. It is fully coupled (atmosphere-ice-ocean).
2. It applies bias corrections to the heat fluxes.
3. It includes a simple ice model focusing on predictability rather than full physics.
4. It is an ensemble to minimize random flux errors.
5. It includes new skill metrics, particularly designed for ice products and their users.

The economy of such a model, in light of limited compute resources at NOAA, suggests a regional approach with modest resolution. Operational sustainability suggests the use of existing modeling tools within NEMS, implying a regional Nonhydrostatic Multiscale Model on B-grid (NMMB) mesoscale weather model coupled to a regional HYCOM ocean model. This also suggests a modest initial forecast range of 5-7 days, allowing an assessment of this modeling approach compared to the present ACNFS, as well as persistence with respect to ice concentration of ice edge forecasting. Such a model could initially be implemented as a stand-alone new model at NCEP, but has a clear path of integration into existing modeling systems such as the GEFS and GFS as it uses common building blocks in NEMS. Note that the Navy followed a similar path with ACNFS, by first developing this as a separate model with a focus on upgrading the ice model, and is now merging this model back into their operational Global Ocean Forecast System (GOFS 3.1).
An additional option, pending available resources, includes considering coupling a wave model into this system, both for experimenting with wave coupling, and evaluating whether wave momentum has a direct impact on ice drift in the marginal ice zone. As this is not a critical element of the arctic work plan, wave coupling will not be considered in detail in activities described below.

- The key to efficiently building this experimental coupled model is the use of existing building blocks in NEMS. For the ocean model, an Arctic subset of the grid of RTOFS-global will be used, with the latter model providing the lateral boundary conditions. For the atmosphere, a regional

NMMB model will be used, nested in the GFS for the initial deterministic setup, and in the GEFS for the final ensemble setup. The two models will use the same ice concentration data from the KISS model, which will be initialized using the daily high-resolution ice concentration analysis from NCEP (the latter analysis is used also in the ACNFS, but this system does not use a coupled ocean-atmosphere approach). Considering the present skill of the ACNFS, it is sufficient to initially run this system with a 5-7 day forecast range. This range is somewhat relevant to offshore operations, although there are needs for forecast products in the 1-2 week, 6 week and 6 month ranges. The initial setup of this model allows up to 8 days forecasting with dynamic ocean boundary data from RTOFS-Global, and up to 16 days with weather boundary data from GFS or GEFS (and constant ocean boundary data beyond day 8). After the initial setup of the model at the 5-7 day forecast range, it will be trivial to expand the validation up to day 16, assuming significantly improved compute resources at the end of FY 2015.

- **Lead Organization:** EMC
- **Activities:** Building an experimental Arctic model coupled to both ocean, ice and atmosphere models
- **Milestones and deliverables:**
  - Have a stand-alone NMMB and HYCOM regional model running independently (“solo coupler”) in NEMS environment in four months, along with the first estimate of heat-flux biases based on archived model data, while targeting 5-7 day forecast for initial model testing.
  - Within six months of funding, a KISS v1 model would be running with solo coupler in NEMS.
  - At eight months, a prototype of new metrics for validating Arctic ice model would be provided.
  - Within a year, a demonstration version of a coupled deterministic model will be ready, including KISS v2 with an initial static bias correction.
  - By 16 months, a prototype ensemble model based on the above deterministic model, and with NMMB nested in GEFS, will be finished.
  - At 2 years. The ensemble will be fully tested and ready for operational implementation. Establish reasonable forecast range base on predictab8ility of ice an availability of GEFS boundary data for NNMMB (16 days maximum.)
- **Anticipated collaborating organizations:** TBD
- **Priority:** High
- **Duration:** 2 years
- **Points of contact:** Hendrik Tolman

4.0 Ice Model

NCEP’s two ice models include a simple ice model under development at EMC (KISS) using thermodynamics and simple ice drift approaches sufficient for creating predictability, and is much easier to control than full physical model. Another model, NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL) climate model, known as CM3, is formulated with ocean, ice, atmosphere and land model components.

Ice guidance with a fully coupled ice model is described in detail in the Arctic plan. For collaboration within NOAA, the Great Lakes Environmental Research Laboratory (GLERL) Ice modeling and GFDL climate ice modeling are natural points of collaborations. As collaboration with GLERL is already funded on the short time scales through NOAA's National Ocean Service Coastal Storms, and has a request for long lead time ice funding through OAR ESPC funding, GFDL appears the best candidate to work with on (Arctic) ice modeling, particularly with their existing ice models. Focusing on potential work that can help EMC operations, the following work can be by GFDL:

- Develop sea ice modeling capability in NEMS and other couple models.
    - **Lead Organization:** EMC
    - **Activities:** Collaborate with GFDL for model improvements
    - **Milestones and deliverables:**
        - In Year 1, use the GFDL climate model for "short term" runs to assess ice predictability for 5-7, 16 and 30 day forecasts and 6 week and 6 month forecasts. GFDL could work with EMC on developing sensible ice concentration metrics.
        - In Year 2, as the NCEP Ice model (KISS) becomes fully available in NEMS, test out this model (including flux bias treatments) in one or more GFDL models for longer lead-time climate runs. This will be helpful with respect to assessing the KISS capabilities at longer time scales, as well as with respect to necessary bias corrections for KISS in general month multi_2 global hurricane wave model.
        - By 24 months, it is wave O&M support.
    - **Anticipated collaborating organizations:** GFDL
    - **Priority:** Medium
    - **Duration:** 2 years
    - **Points of contact:** Hendrik Tolman